Adaptive Laser Beam Control Using Return Photon Statistics

Status Report 2
1 March 2005 – 30 May 2005
CLIN 0001AB
Contract No. FA9550-05-C-0010
Nukove Scientific Consulting

prepared for:

Dr. Jon Sjogren, Program Manager

AFOSR/NM

1. Overview

This Status Report, satisfying CLIN 0001AB for the referenced contract, highlights the progress the Nukove Team has made during the second quarter of the Year One effort (1 March 2005 – 30 May 2005). Susan Chandler has had discussions with Mew Mexico State University, and Gordon Lukesh has talked extensively with NMSU statistician Deva Borah. Susan Chandler has had numerous discussions with Woof Consulting, solving the thorny issue of data sharing.

During the referenced period Nukove had continued interactions with experimentalists at Starfire Optical Range (Kirtland AFB, NM) and an important meeting with experimenters at AMOS, Maui, HI, in February. Nukove will participate in an AFRL Program Review for SOR/AMOS efforts June 7-8 and will present analysis based on the RHINO development tool. Nukove has continued funding through AFRL to support data analysis for both sites.

Nukove will present both a poster paper and as well as an <u>invited</u> address at the forthcoming XIIth International Symposium "Atmospheric and Ocean Optics, Atmospheric Physics" (Tomsk, Siberia) at the specific invitation of Dr. Vladimir Lukin. The invited address will introduce the basics of RHINO and the poster presentation will describe two methods of laser system pointing estimation as were detailed in an Applied Optics paper.[1] These results have been extensively examined during the Phase II STTR.

2. Program Status

The program is on track as outlined in the Program Plan delivered December 2004. Nukove was pleased to present a briefing at North Carolina State University, outlining the results and goals of the project. The briefing will provide a foundation for the presentations in Tomsk.

2.1. Nukove Scientific Consulting

Nukove has converted RHINO to Matlab. As much of the underlying analysis, i.e., the development of statistical bin models, is performed in Matlab, purchase of a Matlab compiler at an appropriate time (probably during Year Two) will allow for a completely self-contained package that does not require the end-user to have a Matlab™ license (the legality of this has been verified). GUI investigation continues to be handled by Woof Software Consulting, Colorado Springs, CO.

Susan Chandler has studied the variation in pointing estimates when more than the current 25 shots/five χ^2 bins are used. It appears, and this was suggested by Deva Borah, that the use of 25-50 shots with five bins may provide the best estimates

Nukove continues to analyze data from experiments at both the Starfire Optical Range on Kirtland AFB, NM, and the AMOS facility on Maui. Nukove will participate in an Active Tracking for Discrimination

Program Review June 7-8 and present analysis using the prototype RHINO. Recently Nukove analyzed data from an SOR experiment. The pointing estimates were initially at odds with the experimenters' view, however on further analysis it was shown that the "auto-scaling" of the 48x48 tracker camera data on a frame-by-frame basis had misled the experimenter and in fact the pointing system had wandered off the target. Figure 1 shows the analysis. Because there were only 400 illuminations, RHINO used a 50 moving average and clearly after ~250 shots the jitter estimate changes dramatically. Cooperation and interaction with experimenters at SOR and Maui are invaluable, especially as shown in this "blind test" case.

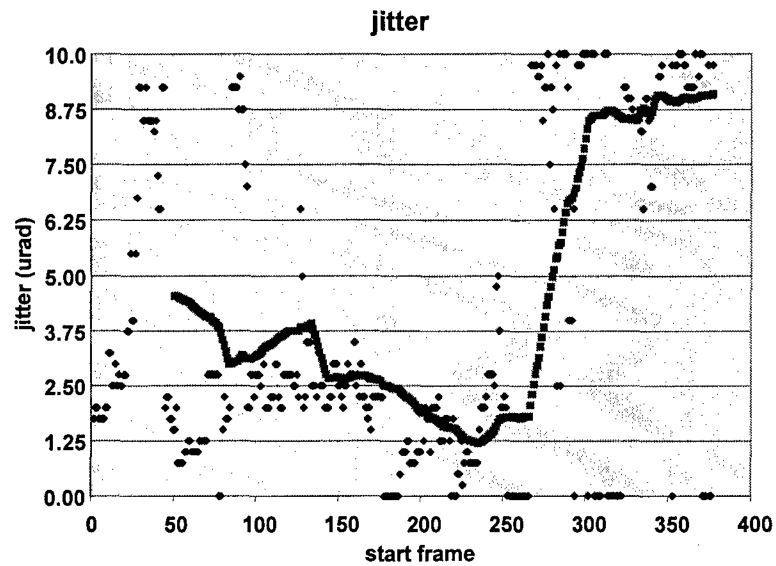

Figure 1 This shows the RHINO pointing estimation for the OAO3 engagement 23 April 2005. The dots represent estimates of jitter based on 25 point moving blocks, while the magenta line is a 50 point moving average. Normally Nukove employs a 200 point moving average but due to the limited number of shots (400) the 50 point option was chosen.

2.2. New Mexico State University

The NMSU efforts included laboratory upgrades, including the purchase of an atmospheric turbulence screen, and statistical analysis under the direction of Dr. Deva Borah including analysis of a maximum likelihood estimator. The efforts were detailed at the NCSU Program Review.

2.2.1. Laboratory Efforts

NMSU incorporated a maximum likelihood estimator for jitter/boresight estimation into LabVIEW. As shown at NCSU, the boresight estimate (with a priori knowledge of the boresight vector) allowed the testbed to effectively reduce boresight to zero. NMSU is currently developing a search algorithm to eliminate the need for boresight vector knowledge (generally not available during an experiment). This is an important middle step; however the ultimate goal is to allow for external experimental data to be fed to RHINO and estimates returned on a real-time basis.

A new fast steering mirror has been implemented in the testbed. The mirror is from Newport and has a bandwidth of ~500Hz. NMSU is testing the mirror for linearity and repeatability. This mirror greatly reduces the data collection time and allows collection of data at 10Hz reducing the collection time to 100 seconds for 1000 samples. NMSU is also designing the LabVIEW software changes to the data collection program.

NMSU ordered the atmospheric phase plate system (Lexitek, Inc.) that will be used on the Testbed to simulate turbulence. NMSU worked with Lexitek to precisely define the phase profile for the plate. As of this writing, the plates are being shipped to NMSU. Characterization will take place.

2.2.2. Statistical Analysis

Dr. Deva Borah determined that another natural approach to boresight and jitter estimation exists. The approach is a maximum likelihood estimator. It is an optimal estimator under certain conditions and is easy to incorporate. However, right now it is valid only under special conditions such as a Gaussian beam and a point target. Further analysis is warranted. For more general situations, the Nukove χ^2 method still appears to be the only practical strategy for extended targets and non-Gaussian beams.

The approach will easily be incorporated into RHINO as it is a closed-form equation. By incorporating this estimator into RHINO, should the analysis confirm good success rate, it will add value to the RHINO by providing an additional estimator.

Dr. Borah will next proceed with an analysis of the Cramer-Rao lower bound for the RHINO, Key Ratio and MLE approaches. This will determine the limits of the methods *vis a vis* estimation of pointing.

2.3. Woof Software Consulting

Woof provided fundamental contributions during the second quarter. Martha Chandler wrote data socket software to allow simultaneous data use by RHINO and LabVIEW. In addition, Chandler recommended, after evaluation, the use of Visual Studio.NET over Matlab as the development platform to ensure that RHINO may be used on a variety of platforms such as PCs, Macs, handhelds and individual chips, with the last critical should a need, for example, in laser communication arise for a scaled down, specialized version of the software. RHINO will also work over a network, essential, for example for the AMOS facility where analysis is often performed at sea level while the experiments take place at 3,200m on Haleakala. An example GUI front page was shown at the NCSU Review.

2.4. Travel

Woof Consulting is four hours away and Nukove has had several visits to talk with Martha Chandler. Nukove plans a trip to NMSU in August for program coordination on this STTR as well as the laser communication efforts.

3. Summary

Considerable progress was made during the second quarter under Phase II. Regular communication between Nukove and NMSU, and with Woof Consulting, has produced tangible results as described in this short Q2 Status Report.

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[1] G. Lukesh, S. Chandler and D.G. Voelz, "Estimation of laser system pointing performance by use of statistics of return photons," Appl. Opt. **39**, 1359-1371, 2000.

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